Source control of manganese (Mn) in a drinking-water supply reservoir: the importance of including geology in watershed management

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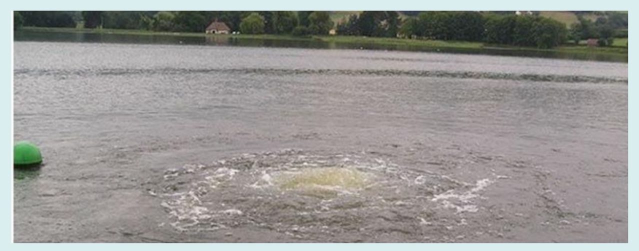
1. Introduction

- Manganese (Mn) is a common and abundant trace metal in rocks and sediment which is currently costing drinking-water utilities (e.g., in the US and UK) millions of USD$ annually due to customer complaints, aesthetic issues regarding taste, odour and colour, and distribution problems related to Mn-driven pipe blockages[1,2] (*Figure 1*).
- Removal of Mn for meeting the US and UK drinking water limit (50 µg/L) is feasible but often difficult and costly using conventional water treatment processes[2].
- Water utilities are actively using in-reservoir, engineered aeration and watershed-focused management in attempt to improve water quality and reduce treatment costs resulting from sub-oxic conditions and subsequent release of soluble chemicals (e.g., Mn) from lake and reservoir sediment (*Figure 2*).
- **Despite these efforts, significant Mn-related water supply issues often persist which may be attributed to the predominant agricultural (i.e., nutrient) focus of watershed management strategies paired with the complexity of Mn biogeochemical cycling.**

Figure 1. Excess levels of manganese (Mn) in drinking water can cause aesthetic issues such as discolouration (a), pipeline degradation (b) and blockages (c).



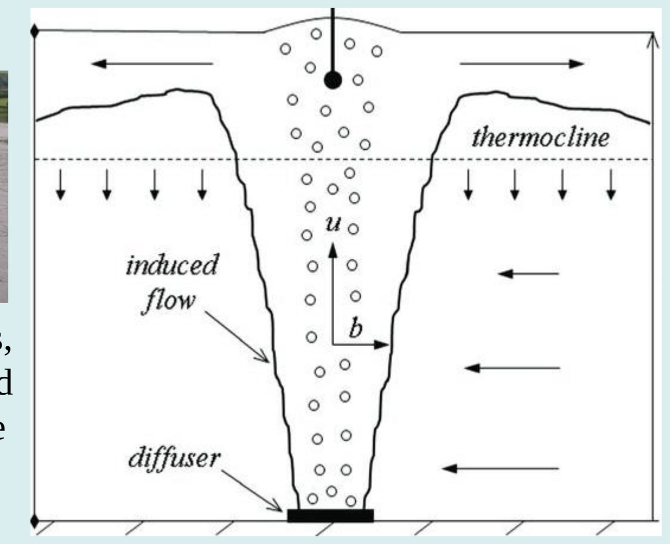


Figure 2. Destratifying aeration systems, e.g., bubble plumes, are prevalently used by UK water utilities. These systems are designed to destabilize the thermocline and fully mix the water column[1].

2. Research objectives

This research focuses on investigating the role geology plays in reservoir water quality and watershed management via mapping of the sources and biogeochemical pathways controlling concentrations of Mn within a reservoir watershed. Specifically, the roles of 1) watershed geology, anthropogenic activity and resultant Mn-laden sediment transport and 2) aeration-induced variations in reservoir water quality are assessed.

3. Study site and methods

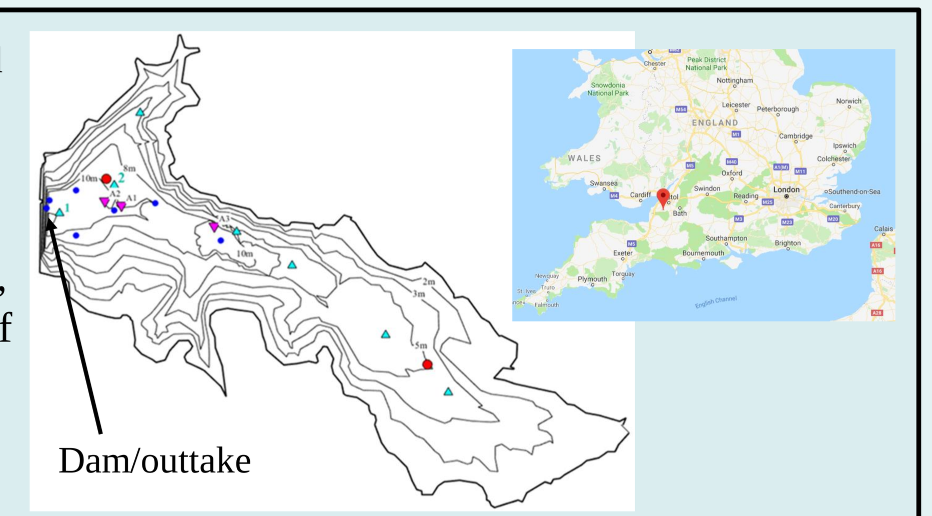


Figure 3. Blagdon Lake (located in Bristol, southwest UK); the contoured schematic indicates the aeration bubble plumes (blue dots), sediment core locations (red dots), and water-column profiling sites (triangles).

The project study site is Blagdon Lake, an aerated drinking-water supply reservoir managed by Bristol Water, located in the south-western region of the United Kingdom (*Figure 3*). The reservoir has a maximum depth of 11 m and volume of 8.5 x 10^9 L. Blagdon Lake is used as a 'natural laboratory' in which oxygen and mixing can be manipulated (via aeration) and correlated to shifts in water-column and sediment Mn concentrations.

Field campaigns in summers 2017 thru 2019 focused on characterising oxygen and Mn dynamics within Blagdon Lake and the surrounding watershed, including a local historic Mn mine (dating back to the early 1900s), on seasonal and catchment-wide scales to establish a reservoir-focused mass balance of oxygen and Mn. Biweekly monitoring included water-column and sediment core sampling for oxygen and Mn (total and soluble) concentrations and YSI-Xylem EXO3 multi-probe water column profiling along a reservoir transect.

Blagdon Lake is equipped with a destratifying bubble-plume aeration system consisting of seven bubble plumes deployed on the bottom sediment. Bubble-plume placement is intended to optimise mixing of reservoir water closest to the dam outtake (Figure 3). Destratifying (i.e., fully mixing) aeration systems are used by almost all UK drinking-water utilities to combat Mn and algae problems in their supply reservoirs (*Figure 4*); conversely, stratification-preserving (i.e., hypolimnetic) aeration/oxygenation systems are commonly used by US utilities.

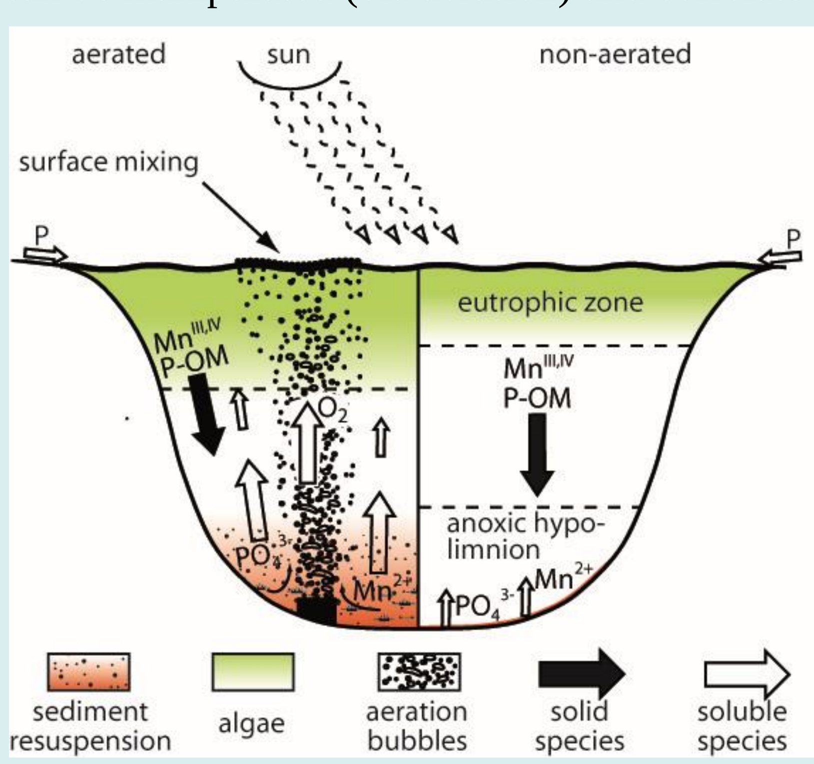


Figure 4. Biogeochemical cycling of Mn, phosphorous (P) and algae as influenced by destratifying aeration (aerated; left-hand side of reservoir schematic) and in natural reservoir systems (non-aerated; right-hand side of reservoir schematic).

4. Results & Discussion

Watershed mass balance results (*Figure 5*) show that local geology and sediment transport within the watershed control reservoir Mn concentrations, with Blagdon Lake behaving largely as a Mn sink. This is particularly critical in the deeper reservoir region near the dam and treatment-plant outtake where bubble-plume aerators are creating high levels of sediment resuspension, as indicated by reduced oxygen near the sediment and in regions of the bubble plumes (*Figure 6*). A direct correlation between the start of Blagdon aeration in the mid 1990s, decreased water-column Mn (*Figure 7a*) and increased Mn concentrations in reservoir sediment is observed, highlighting that aeration is having an influence on sediment retention of influent catchment Mn (*Figure 7b*).

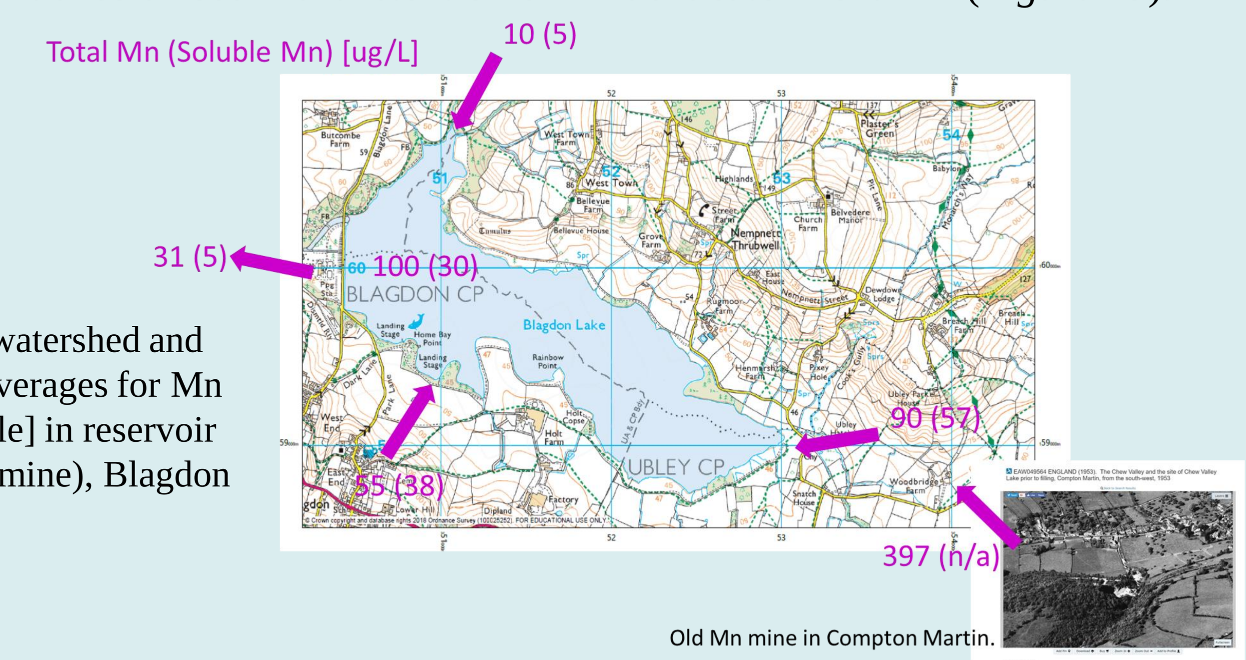


Figure 5. A Mn mass balance of the Blagdon watershed and reservoir was performed based on measured averages for Mn [total Mn (soluble Mn) concentrations in purple] in reservoir inflows (including rivers and runoff from Mn mine), Blagdon source water, and downstream from dam.

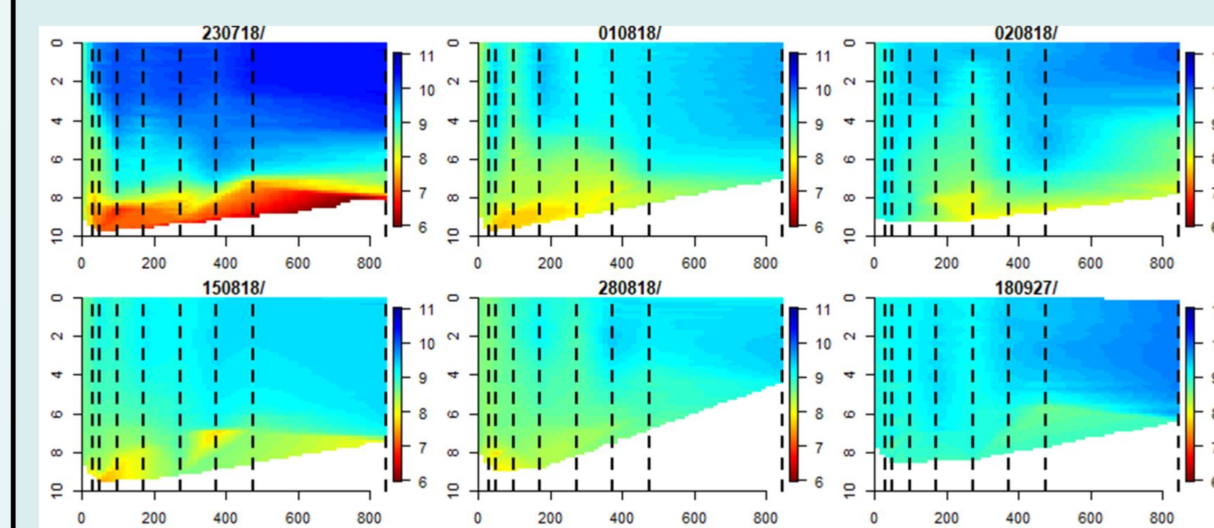
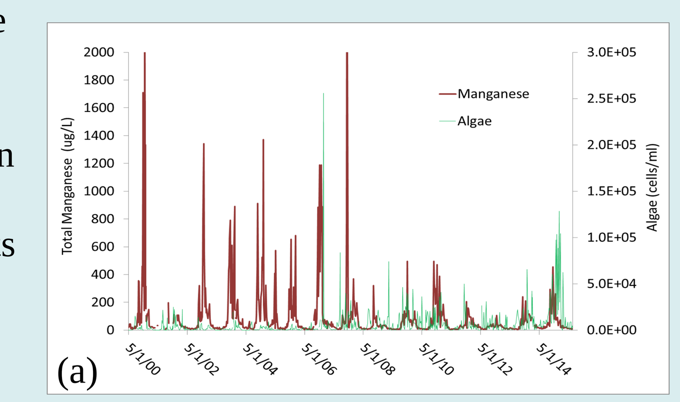


Figure 6. Water-column EXO3 profiles along reservoir transect (measurement sites shown by vertical dashed lines in *Fig. 6*; triangles in *Fig. 3*) show decreased oxygen in bottom water and at plume locations (e.g., at distance 50 m and 300 m along x-axes) which may be attributed to sediment resuspension via plume mixing. Note 1) absence of stratification and 2) increased homogenization and decreased oxygen concentrations as summer aeration progresses.



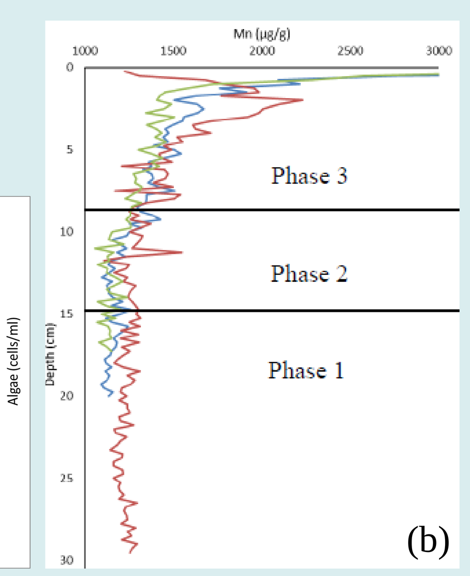


Figure 7. (a) Historical data showing concentrations of Mn and algae at the dam outtake indicate a considerable decrease in Mn (albeit with a corresponding increase in algae) corresponding to the conversion of reservoir aeration to bubble plumes in 2007. (b) Mn concentration data (obtained via x-ray diffraction of sediment cores taken along reservoir transect; sites indicated by red dots in *Fig. 3*) show increased sediment Mn in coordination with aeration via linear diffuser in mid 1990s (Phase 2) and current bubble-plume system since 2007 (Phase 3).

5. Conclusions

- Initial results show that local geology and sediment transport within the watershed control Mn concentrations in Blagdon Lake, which behaves as a Mn sink. These results are highly relevant for the optimisation of reservoir aeration, comprehensive watershed management and sustainable drinking-water supplies.
- Work is ongoing to develop future management strategies that minimise detrimental impacts of naturally occurring biogeochemical processes as well as optimising technical solutions, such as engineered aeration, to ultimately better protect our drinking water supplies more sustainably.

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Acknowledgments

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